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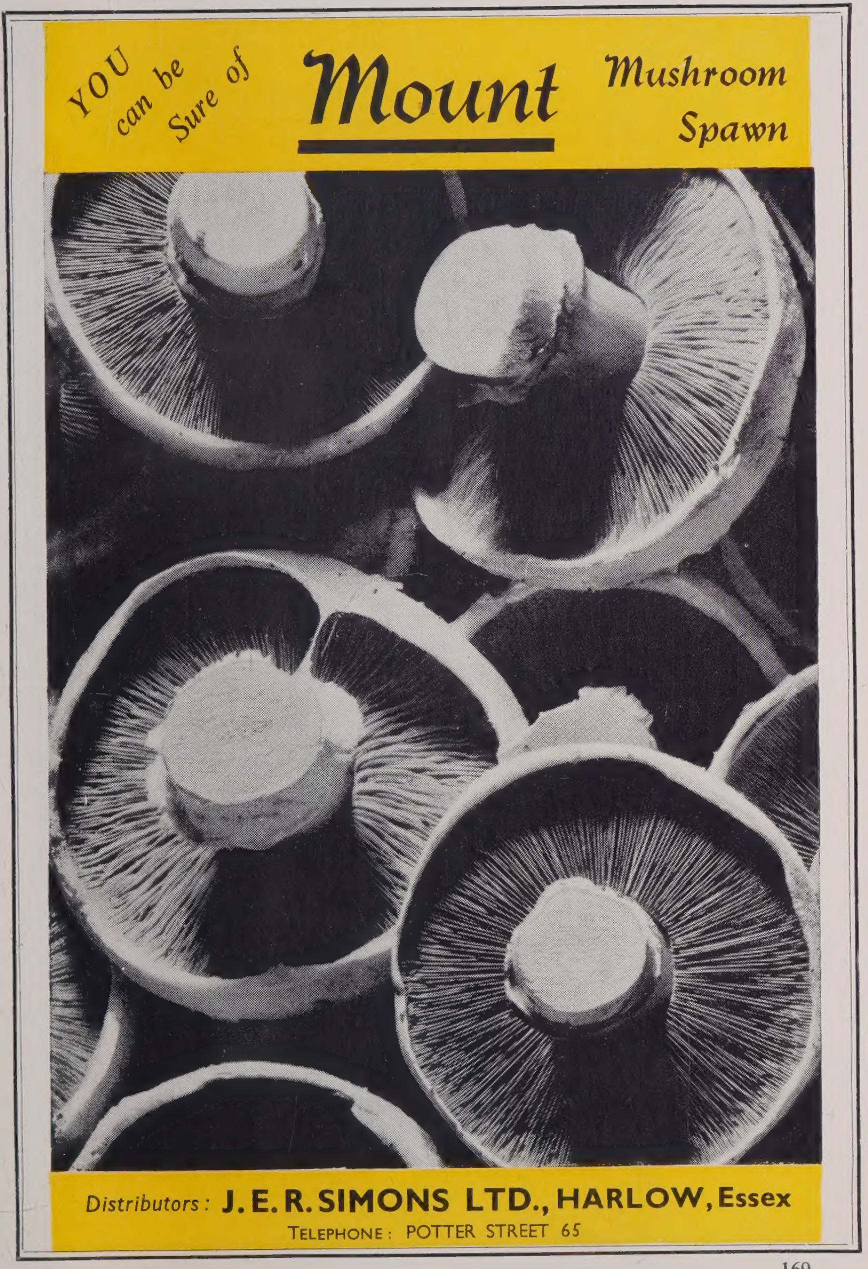
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The
MGA BULLETIN

JUNE · 1953
NUMBER 42

EDITORIAL

Welcome to
OUR NEW SECRETARY

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Angus Watson having resigned in order to become a grower, PERCY F. ANDERSON, F.J.I., F.R.H.S., has been appointed. He is a native of Warwick and comes of agricultural stock.

A qualified Company Secretary, he was Secretary Accountant to the B.B.C. on its formation as a limited company prior to granting of the Charter, and was in at the birth of the *Radio Times*, *World Radio* and the *Listener*.

Later he joined the British Legion at Headquarters as Press Secretary.

A member of the Institute of Journalists since 1928, he was elected a Fellow in 1939 and was for some time a member of the Council and Chairman of the London District Economic Committee.

A keen Territorial, he served in both Wars, was Garrison Adjutant at Calais after V.E. Day and remained to close down the British Army Garrison in the North of France.

A THEORY OF COMPOSTING

BASED ON THE INVERSE YIELD-NITROGEN LAW

By **Dr. B. B. STOLLER**

This is a theoretical discussion, but it has a practical objective—how to account for the large yields of mushrooms obtained recently by two groups of American investigators. One consolation about this discussion of theory of composting is that the theory can easily be tested experimentally, and either confirmed or rejected.

Last year Lambert and Ayers (4, 5) reported an extensive investigation in which the yields of mushrooms were over 500 lb. per ton of manure. Another report of yields of about 800 lb. per ton of manure was briefly mentioned by Sinden and Hauser (9) in their discussion of short methods of composting. By the usual commercial practice, it is possible to obtain 200 to 350 lb. of mushrooms per ton of manure, so the yields of these investigators are remarkable. Both Lambert and Sinden have been engaged in experimenting with mushroom composts some 20 years, so it may be assumed that the results they reported independently are authentic.

The explanation for these high yields by Sinden and Hauser is, essentially, that in composting by their procedure the loss in dry matter is low and proteins are conserved, so that more of the essential nutrients are available for greater production. Lambert and Ayers, however, emphasize the destruction of insects and other pests by the very high temperatures employed initially in their process, along with a conservation of nutrients. While the factors mentioned by these investigators do enter into any explanation for these high yields, the writer is inclined to theorize that the most important factors are a high C : N ratio and a high K : N ratio; that is, maintaining a high percentage of carbonaceous material compared with a relatively low amount of nitrogen; and that with increase of C, and so getting a *relative* decrease of N, the potash, K, must be sharply increased. This view, it must be admitted, is a departure from the writer's previous generalizations about the N in composts (11). A change and extension of previous formulations are required in order to account for the high yields mentioned above. An explanation for these high yields may be derived by a consideration of the "Inverse Yield-Nitrogen Law" and K : N ratio, to be described later. Before proceeding with an analysis of the factors involved, the principles and techniques for composting will be discussed briefly; a complete review is now in press (14).

Principles of Composting

The function of composting is to make the substrate unsuitable for competing micro-organisms yet, at the same time, favourable for the growth of the mushroom mycelium and for the largest production of

sporophores. During composting, Waksman and Nissen (18) explain, microbes growing in the compost consume water-soluble substances, more or less cellulosic substances, but use little of the lignins, so that the latter along with the microbial proteins tend to accumulate. They find that the mushroom does not use the " compost as a whole for its nutrition," but prefers the substances accumulating, namely, the lignins and organic nitrogen complexes. From their data on pure culture, it is evident that the mycelium can utilize all the fractions of the carbonaceous substrate, but prefers lignins.

On the contrary, Treschow (16) observed in pure culture studies that xylose, a hemicellulose hydrolytic product, was more suitable than other sources of carbon. He considered the decrease in hemicellulose during composting " a big minus ". The purpose of composting, he reasoned, was not to accumulate lignin, but to reduce the large amount of ammonia in fresh manure, by converting it partly to microbial protein and by evaporating the rest, so that conditions favourable to mycelial growth were created.

Treschow's conclusions (16) in regards to the unnecessary losses of carbonaceous materials and dry weight during composting appear to be warranted by recent experimentation. But his deduction " that only through this composting process it is practical to lower the always great ammonia content of fresh horse manure to a level at which the growth of the mushroom mycelium is possible ", is not supported by practical experiments with liquorice root composts (11). The ammonia evolving from fresh horse manure is produced by the action of " urea bacteria " on the water-soluble nitrogen, largely urea. (" Urea bacteria " are easily isolated from fresh manure by culture on a urea-enriched medium (12)). Stoller (11, 12) has shown that urea can be utilized by the mushroom mycelium without, apparently, conversion to proteins or evaporation as NH_3 (relative to amount present in manure), if the urea is mixed or ' combined ' with lignin or tannin to prevent " urea bacteria " from forming toxic, free ammonia. Furthermore, it was shown also in preparing liquorice root composts, that by the addition of small amounts of cheese whey (70% lactose) the yields of the composts containing urea as the sole source of N were increased from 0·84 to 2·24 lb. per sq. ft. (11). It is well-known that acidifying and carbohydrate materials like lactose, lignin and tannin will suppress the growth of " urea " bacteria, even in a urea-enriched media. Another interesting result in connection with ammonification is that liquorice root composts prepared with $(NH_4)_2SO_4$ as the sole source of N (containing O·5% N as ammonium salt or 47·5 lb. $(NH_4)_2SO_4$ per ton—wet basis) ammoniated so strongly and continuously throughout the cropping period that even the mycelium failed to grow in the compost ; however, when a small amount of cheese whey was added to a similar compost, the yield was 1·84 lb. per sq. ft. (11). This rather spectacular effect of relatively small amounts of cheese whey and lignin-tannin to make available to the mycelium what would be otherwise toxic ammonifying salt or urea was clearly demonstrated; because the effect of cheese whey was not emphasized in the previous publication (11), it was overlooked by Sinden (8) and Edwards (1) in their criticism of the writer's conclusions regarding the sources of nitrogen for composts.

From this discussion of composts it might be concluded that, if competing micro-organisms could be prevented from interfering, the mycelium could utilize all the constituents of the fresh manure. So it would seem, as Treschow (16) has stated, " composting is no absolutely indispensable requirement for mycelial growth." Methods of preparing composts with select materials, in which there is no resort to composting or fermenting, except that which occurs during the short " pasteurizing process," have been suggested and have resulted in good yields (10, 11). But in most experimentation and practice, a " short " composting period of less than 15 days is resorted to (11, 9, 5), in which a loss in dry weight of 10% to 35% is incurred. As a result of this loss, the lignins do tend to accumulate; nevertheless, the cellulosic materials are not reduced as much as in a longer period of composting.

The extent or duration of composting will depend on the effect of the factors developed during composting for inhibiting competing micro-organisms ; that is, upon the accumulation of lignin, reduction in cellulosic materials and in water-soluble nitrogen, so that conditions for the growth of competitors like *Chaetomium* and " urea bacteria " are made unfavourable. By having resource to adjuvants like gypsum, cheese whey, lignin, tannin, etc. the duration of composting could be reduced because there would be less dependence upon the factors naturally developed during composting for suppressing competitors.

Techniques of " Short Methods " of Composting

The first attempt to shorten the duration of composting was made by Stoller, Smith and Brown (15) prior to 1937. A slowly revolving drum was provided with means for forced aeration so that the aeration and temperature could be controlled in order to obtain a rapid, high-temperature fermentation. The naturally high temperatures developing in fresh manure or synthetic compost of cornstalks were controlled by altering the rate of aeration; the temperature was allowed to gradually increase from 95° to a maximum of 145° F. and then back to 104° over 7 or 10 days. The manure and cornstalks were composted with a loss of dry weight of 20% to 28% in 7 days; a normal yield of mushrooms was obtained. While the practicality of this apparatus was questioned, *the principle was demonstrated that with better aeration and mixing of the compost, the duration of composting could be shortened.*

Later, Lambert (2) in 1938-41 conducted experiments in quart jars and observed that fresh manure could be converted into composts suitable for mycelial growth in about 10 days if the temperature is maintained between 120° and 140°, the moisture controlled by adding superphosphate or gypsum; the rate of aeration was not controlled but assured by diffusion. The loss in dry weight was about 32% in 10 days. In 1950 Sinden and Hauser (9) described experiments conducted 10 years earlier in two-quart jars with arrangement for aeration at 140° F. Two rates of aeration were attempted, one rate six times faster than the other. At the lower rate of aeration the loss in organic matter (which is greater than the calculation for loss in dry weight) was 19%; at the higher rate, 37%. Growth of mushroom mycelium was poor unless

compost was extracted with water. It should be evident from this discussion that the experimental basis for a short method of composting was established before Sinden and Hauser started their experiments, despite the implication of the "experimental basis" for their "system".

The principle of better aeration and mixing to shorten the duration of composting was applied to plot experiments by employing liquorice root composts by Stoller in 1936 to 1941: he published results in 1943 (11); by Lambert with manure and gypsum in 1938: he published results in 1941 (2, 3); and by Sinden and Hauser also with manure and gypsum presumably 10 years previous to their publication in 1950 (9).

One of the factors of importance in "short methods" is the moisture content of the compost. Composting, or the decomposition of plant materials, is essentially a hydrolytic process, that is, adding water to hydrolyze the carbonaceous materials (microbiologically for the most part) and so reverse the condensation process by which the plant materials were formed. Also, with better aeration, more moisture is required to replace losses. With liquorice root composts, the problem of moisture is not apparent because the roots as received from the manufacturer of liquorice contain about 220% moisture, and even after pasteurizing contain 200%. The fibrous roots are firm even as subdivided; there is no tendency for the roots to become soggy as straw may become at high moisture. For manure with its straw bedding, the question of moisture at start of composting is of paramount importance. It is to Lambert's credit that he was clearly cognizant of this fact, and suggested increasing the moisture to 250% at the start of composting. Upon publication of Pizer's information on the flocculation and water-controlling effect of gypsum (7), Lambert (3) applied this information to increase the moisture content of manure composts, so that the duration of composting could be shortened and the quantity of manure per bed area extended. (The usefulness of gypsum, it seems to the writer, is not only to control the absorption of moisture, but also to help suppress the urea bacteria by its acidifying effect.) In his experiments, Lambert found that by mixing superphosphate or gypsum with fresh manure, preferably chopped, adding water to 250% moisture, and filling the beds immediately, the fermentation could be reduced to 12 days, the bed area filled to 200 sq. ft. per ton of manure, and the yield was 1·75 lb. per sq. ft. or 350 lb. per ton. The difficulties with his method was that watering and mixing had to be done in the beds, and the temperature had to be lowered and raised again to do it. However, he clearly realized that in commercial practice the outdoor composting could be "reduced to 2 or 3 turnings at rapid intervals" so that the necessity for working in the beds could be eliminated.

The next important factor in short methods of composting is controlling the aeration and temperature of the compost heap. A drum, as described above, would be ideal if an apparatus of this kind were practical. But in the compost heap, as stated by Lambert (2), "the physical conditions (temperature, moisture, and aeration) are dependent largely on the size, shape and compactness of the heap", although he did not give an experimental demonstration of these dependencies.

Stoller (11) in his experiments with liquorice roots described experiments on the principle of the relation of size of pile to aeration, duration of composting, and effect on yield. With small piles yields of 2·5 lb. per sq. ft. were obtained, but with large piles, even though the base was only 9 ft. and height 4 to 5 ft., the yield was reduced to 1·5 lb. It was evident that with small piles the surface exposure was relatively large and the " core " of the pile was relatively small so that good aeration was obtained; for large piles, the conditions were the reverse. This condition of the large piles was corrected by placing a " ventilator " in the centre at the bottom of the pile (use of ventilators under compost heaps is a well-known practice). Diagrams and conditions in the piles (moisture, pH, temperature, CO_2 and O_2) with and without ventilators were illustrated.

Experiments on the effect of the duration of composting on the yield were devised with small piles of liquorice root composts (about ½ ton); that is, under conditions of good aeration. A yield of 2·85 lb. per sq. ft. was obtained after composting for 8 days and turning the compost twice. The yield was decreased to 2·55 lb. by composting 16 days and 3 turnings; by composting only 2 days and 1 turning, the yield was reduced to 1·5 lb. and all kinds of mould growth encouraged. It is possible that with better means for mixing and aerating the duration of composting, at least with roots, can be reduced to less than 8 days and still obtain large yields. But with large piles, it was stated (11) proper mixing, watering and aeration were not as easily managed, so that 15 to 20 days were required for composting. However, with the recent advent of the tractor-loader or the newer automatic self-feeding loaders and turners, mixing and aeration could be accomplished as effectively in large piles as in small ones, so that the duration of composting, at least with roots, would not need to be longer than 8 days.

The " short composting system " described by Sinden and Hauser (9) pertains to the two " important objects ": (1) Bringing up the moisture at the beginning of composting to 250% and then adding supplements such as gypsum or protein, and (2) facilitating aeration of compost and preventing the anaerobic " core " by keeping the cross-section of the pile small. This " system " is not fundamentally different than the process described by Stoller (11) above with liquorice root composts; except, employing manure instead of roots, they adopted Lambert's method (3) described above, pertaining to an initial moisture of 250% and the use of gypsum. Judging by the two " important objects " of their " system ", it is not apparent to the writer where they have introduced any new principles in the short method of composting; their system may be characterized as a " variation " of Lambert's procedure. The fact that Sinden and Hauser (9) made no reference to previous publications on mushroom research is probably contributory to Sinden being erroneously referred to by some writers and growers as the originator of the " short method " of composting. But it does seem to the writer that Sinden and Hauser have made a notable contribution in their last experiment, which was briefly reported, on the production of 800 lb. of mushrooms per ton of manure; this experiment will be discussed later.

The Importance of High Carbon in Compost

From laboratory-scale experiments on composting (15, 2, 9) it is evident that the loss in dry weight is dependent not only on duration of composting, but also on the temperature and rate of aeration. With outdoor composting only the duration can be completely controlled. Arranging the size of the pile will tend to reduce variations due to the effects of temperature and aeration, but will not eliminate them. So it is not surprising that in one set of data reported by Sinden and Hauser (9) there is a gradual decrease in bed space filled as the duration of composting is increased from 7 to 27 days, whereas in another set of data there is no such clear distinction. In order to account for their yields of 700 to 800 lb. per ton, or yields recently reported by Lambert and Ayers (5) of over 500 lb. per ton, the per cent. loss of dry weight would necessarily have to be low. Sinden and Hauser's method to counteract the effects of ammoniation and susceptibility of the compost to *Chaetomium* is to make loose, shallow beds (assumed to be about 400 sq. ft. per ton according to their data of an average of 2 lb. per sq. ft. or 800 lb. per ton). Lambert and Ayers make deeper beds (73 to 146 sq. ft. per ton) and allow the NH_3 to be dispelled, more or less, by holding the temperature at about 115° F. for 5 days; in order to arrange for longer cropping period, the beds are initially heated to 150° F. to destroy pests. The principle, however, is the same—a high carbon content of the compost. Previously the amount of fixed carbon in the compost was assumed (i.e., taken for granted without testing) to be more than sufficient, and the function of the fibrous material was considered chiefly to provide an aerobic substrate. The significance of high carbon in the compost was foreshadowed by Treschow (16), predicted by Sinden (8), and empirically, but not functionally, shown in experiments by Sinden and Hauser (9).

A high moisture content is required with a high carbon compost (9, 5) and the yield is increased with a higher percentage of moisture (5); however, the liquorice roots had 66% moisture (200% on basis of solids present), still the maximum yield was 360 lb. per ton (11). It might be judged from Lambert and Ayers' experiments that had there been better eradication of insects, the yields with the root composts might have been greater. On the other hand, it was shown that the highest yields with the roots were obtained when organic N materials " served also as a source of carbon " (11), and that with inorganic N substances it was suggested to add " very finely ground straw or corn cobs " besides cheese whey (11). The higher yields with organic N would indicate, then, that the roots were deficient in available carbon. Actually, the liquorice roots have less readily available carbon sources; for example, the content of hemicelloses in liquorice roots are 1/3 of straw and 1/2 of manure; besides, roots have twice as much lignin as straw or fresh manure. So it seems (at least it is the thesis of this paper) that the more available carbon—the celluloses—is the basic, critical element involved. This factor was not appreciated (" unpremeditated ") when conducting experiments with liquorice roots.

Manure consists of approx. 50% finely ground carbonaceous particles (droppings) that have undergone alkaline hydrolysis in the

horse's alimentary tract, and 50% straw from the bedding. These particles of the droppings probably provide the thermophilic microbes with the source of energy to coat or corrode the surface of the straw, making it less available to competitors. To prepare synthetic composts, it seems, it would be required to finely sub-divide, and treat, some of the C sources in rapid composting methods. It would be necessary also to provide means for helping the suppression of ammonification by use of gypsum, cheese whey, etc. and maintaining a high moisture to provide a source of hydrogen ions for ionization and for hydrolysis.

It is possible that, in the loose shallow beds (400 sq. ft. per ton of manure) as may be presumed from Sinden and Hauser's data, the aeration may be more intense so that the growth of urea bacteria might be suppressed by the encouragement of other microbial growth. If the urea bacteria were suppressed, *Chaetomium* would also probably fail to grow or grow weakly; the writer has observed that a slight ammoniation is favourable to the growth of *Chaetomium*. Under these circumstances, then, gypsum or other adjuvants may not be required. But the fact of the matter is that their yields of 800 lb. per ton were obtained when gypsum was employed as a " supplement ".

The C : N Ratio

Sinden and Hauser (9) explain their results on the basis of a low loss in dry matter and in conserving protein; however, this explanation is insufficient in the absence of a high C : N ratio. There are no data available to show precisely the effect of duration of composting and productivity compared to the C : N ratio of the compost. But it may be judged from Tables 3 to 5 of Sinden and Hauser's data that the ratio of organic matter to protein decreased from 6 : 1 to 4 : 1 as the duration of composting is increased from 7 to 27 days. The decrease in yield corresponded to the increase in duration of composting. So this is some evidence that the carbon or organic matter must remain large in proportion to the nitrogen or protein in order to obtain the largest yields. Accordingly, the proportion of C to N must remain large, *i.e.*, a high C : N ratio is a requisite for high yields. The significance of this assertion is shown when taking into consideration the Inverse yield-N law.

The Inverse Yield-Nitrogen Law

According to the " Inverse Yield-Nitrogen Law " (19, 20), the yielding ability or producing capacity possessed by a variety of plant is inversely proportional to the percentage of N contained in its total dry weight. This means that the yield of mushrooms will be greater when the percentage of N present in the mushroom or sporophore is less. In other words, when plants are fertilized with too much N, the plant crop contains more N, but the total dry weight or yield is less. So far as is known this " law " applies to all kinds of plants. It seems to the writer that this law should be more clearly evident in the case of mushrooms than for other plants, because the effect of the fixed carbon and the C : N ratio is known in advance; that is, when there is more carbonaceous material present in the compost and comparatively less N, the same circumstances will be reflected in the sporophores. So that

there will be more sporophores (larger yield) because more carbon is available, but the percentage of N of the sporophore will be less. Whether the addition of more nitrogen to the compost which contained the maximum amount of carbon would depress the yield of mushrooms will have to be determined by experiment. According to the Principle of Limiting Factors, to be discussed later, the addition of more N would have no effect, after the maximum is determined for a given C : N ratio. (If the additional N resulted in ammonification, the effect would be obviously deleterious.)

Some evidence favourable to this law was obtained by comparing the yields and the analyses of mushrooms grown on a synthetic compost almost completely devoid of potash to mushrooms grown on a similar compost supplied with normal amounts of potash (13). It was evident from the data that the yield was much greater when the mushrooms contained less N. For example the yield was 178% greater from the normal compost wherein the mushrooms contained 6·96% N, compared to 7·42% N of the mushrooms from the K-deficient and poor-yielding compost. So here is an indication of a definite inverse correlation in mushrooms between yield and percentage of N. But this evidence depends upon a severe K deficiency, so the data is not offered as a confirmation of this law. The principle is clearly evident, though, that the percentages of N, P, and K of the sporophore are variables which are dependent upon the specification of the compost. However, a difference of 0·46% (7·42 minus 6·96) is immense and could account for the large difference in yields of 178%. In Willcox's data (20), N differences of only 0·01% to 0·02% are indicative of significant differences in yield of plant crops. In future experimentation, this law can be confirmed (dry basis) by analyzing the sporophores for N; if it is found that the % N of the sporophores decreases as the yield increases per quantity of compost, then that would be a confirmation of the operation of this law. If it were confirmed, it would be possible to eliminate many sources of errors in conducting cropping experiments.

TABLE 1. Composition of Mushrooms Grown on a Potash-deficient Compost and on a Normal Compost (13)

Compost	Total N %	Total P %	Total K %	Ash %
Normal	6.96	1.40	5.48	13.4
K-deficient	7.42	1.56	4.90	13.3

The K : N ratio of Composts

It has been shown rather conclusively by Turner and Henry (17) in experiments with green plants that N and K are inversely related. In other words, under circumstances found favourable for plant growth by reducing the amount of N, the plant had a much greater requirement for K; and *vice versa*. To apply this information to mushroom culture, it would be required greatly to increase the amount of K as the N was diluted by a large amount of C.

Some evidence for an inverse K : N ratio in mushrooms was mentioned in connection with mushrooms growing on a K-deficient compost (13), as shown in Table 1. Mushrooms analysing low in K were high in N and P, and conversely. The difference in N and K in the compost is, of course, much greater than is shown in the analysis of the mushrooms. To confirm this kind of inverse correlation, it would be necessary to conduct experiments with a series of variable K : N ratios.

Instead of depending upon the inverse relation of % N to yield in order to determine the yield potentiality of a compost, as stated above, it may be more useful to determine the inverse percentages of K and N. In other words, if the % K is relatively high, and the % N low, then the yield should be comparatively high. This procedure may be more accurate than merely comparing the % N of sporophores from different composts, since the % K and % N is determined in the *same mushroom or sporophore specimen.*

It is known that manure contains a very large amount of potash. It is suggested that the reason for the previous investigators (5, 9) obtaining such high yields with reduced composting of manure, is not only by means of a high C : N ratio, but also due to the fact (fortunate for them) that manure contains large amounts of potash. Accordingly, to obtain a high yield by a short method of composting, the compost should be high in C, relatively low in N, and relatively high in K; *i.e.* a high C : N ratio and a high K : N ratio. The proportions of NPK in manure, 2·0 : 1·0 : 2·7, may be the basis of preparing composts with a high C : N ratio. The ratio, 3 : 1 : 2, found satisfactory by Stoller (11) for liquorice roots, is probably accountable by the fact that the roots, as previously mentioned, contain less readily available C sources than manure.

Principle of Limiting Factors

In agricultural practice it is well-known that a definite inter-relationship exists between the three major plant nutrients—N, P and K. In current fertilizer practice, ratios of NPK are formulated for specific crops, specified soil conditions, etc. In 1843 Liebig (6, 19) proposed his well-known " law of the minimum " as a guiding principle for formulating the use of fertilizers. According to Liebig's Law, an increase in the factor present in the minimum amount will produce an increase in the yield of a crop. While it is true that an increase in this minimum factor will have the greatest effect on the increase in yield, other factors not present in minimum amounts can also influence the yield. For this reason Mitscherlich conceived the operation of " limiting factors " besides the minimum factor. In 1909 Mitscherlich proposed the " Principle of Limiting Factors," which has been stated as follows : " The increase in any crop produced by a unit increment of a deficient factor is proportional to the decrement of that factor from the maximum " (6). In other words, any deficient factor will influence the yield in proportion to its decrement from its maximum effect.

The question is how is it to be known that any specified factor, say N, P, or K, has been used in its maximum or " optimum " amount?

Willcox (19) points out that " an increase in the supply of one plant nutrient (within agrobiologic limits) proportionally stimulates the use of another nutrient, the supply of which has not been increased." He proposes a " fertility index " which is equal to the multiple of all the factors; for example, $F(N) \times F(P) \times F(K) \ldots\ldots =$ Fertility index. It seems there is an interrelationship between all the factors. The decrement of each factor from the maximum influences the maximum yield possible; unless the multiple of the optimum of each factor is considered, the maximum yield will not be determined.

The importance of this principle is evident when attempting to determine the " optimum " quantities of NPK for a compost with a given or specified content of carbon. (In specifying the carbon content of a compost it is understood that the technique of composting—the subdivision of fibrous materials, duration, temperature and aeration during composting, etc., will be taken into account as limiting factors.) It has been suggested how the " optimum " amount of N may vary with the carbon content, as in the C : N ratio. It has been described how the N will vary inversely as the K; and how the " optimum " amount of K will be increased as the N is diluted by an increase of C. From Table 1 it might be guessed that the " optimum " amounts for P will vary similarly as for N. It might be surmised also, from Table 1, that K and N-P are in reciprocal relation; if one factor is deficient, more of the other factor will be used by the mushroom. So it is evident that there is an interrelationship among all the factors; the " optimum " amount of a single factor is dependent upon the " optimum " amounts of other factors.

In view of the preceding discussion, Sinden's (8) claim to have determined the " optimum amounts " of calcium cyanamide, urea, and potassium for synthetic composts is not significant. Concerning his (Sinden's) choice of N sources for the investigation of optimum requirements of N the writer (11) described the qualifications for the use of these N sources, and warned that calcium cyanamide tends to form calcium dicyanodiamide, which is extremely toxic to mycelial growth. Edwards reported a " complete failure " in the use of calcium cyanamide. In the use of urea, a rapid ammonification develops, which prevents composting and later inhibits mycelial growth due to the free ammonia, unless urea is employed along with cheese whey, etc., as previously described (11). So that Sinden did not establish the " optimum amounts " of these N sources; what he found was the toxic effect of these substances as " limiting factors."

The use of calcium cyanamide as a N source in determining the " optimum concentration " of potassium is unsatisfactory, as may be judged from Sinden's statement that " a compost containing an optimum amount of calcium cyanamide will not produce a much higher yield when potassium is added." Sinden censured the writer (11) for not having determined the " optimum amount " of potassium. In his experiments the writer referred to the effects of K only as per cent. increase in yield, because it was realized too many " limiting factors " not under control existed; so that claims about determining " optimum

amounts " would be useless. The only quantities referred to by the writer were those proposed as a working formula.

The Principle of Limiting Factors is the guiding principle in NPK formulations such as suggested by the writer (11). If the technique of composting, and all the elements that enter into this procedure, are standardized, the NPK formulations can be as useful in mushroom culture as such formulations are in many fields of agriculture. In preparing synthetic composts it is necessary to have a formula, *i.e.* a ratio of N to P to K, in which the least expensive by-product on the market, *especially nitrogen sources*, may be used.

Stoller (11) found that " synthetic composts prepared from *many* different sources of N, P_2O_5, and K_2O gave equally good yields." In substantiation of this statement, data was presented in which 17 different sources of N were tested; the yields were 2 lb. or more per sq. ft. from 12 of the 17 sources, with three the yields were $1\frac{3}{4}$ lb., and with the last two, a yield of $1\frac{1}{2}$ lb. Sinden (8) misconstrued the quotation above, stating, " he (Stoller) assumed that the mushroom will be capable of utilizing equally well *any* compost having this NPK ratio, regardless of the nature of the compounds supplying these elements." There is a decided difference between reference to " many " (11) and " any " (8). Furthermore, as previously mentioned, Sinden missed the striking effect of cheese whey in which a compost containing ammonium sulphate as source of N was transformed from producing no yield at all to a yield of 1·84 lb. per sq. ft.; a similar effect was produced by the use of cheese whey with urea. Thus, by taking cognizance of the correcting effect of the cheese whey, the yields from composts with different N sources are not as variable as inferred by Sinden.

To summarize, many different sources of nitrogen may be used equally well. Qualifications in the use of some N sources have been described (11). " The selection of a suitable nitrogen source also depends, of course, on the cost of the material compared to the yield of mushrooms obtained by its use " (11). So selection of nitrogen sources, in most cases, should not be a barrier in NPK formulations.

A final word about NPK formulations and the Inverse Yield-N Law. The writer is not in accord with Willcox (19) that an ideal formula for all plants is N-P_2O_5—K_2O as 5—1—2. It seems Willcox does not take into consideration the fixed carbon, which would be difficult to do, since the amount and quality of light is so variable. But in the case of mushrooms and composts, the amount of fixed carbon for a specified NPK formulation can be determined. So it should be possible in mushroom culture to establish a specified NPK formulation for a given amount of fixed carbon. The Inverse Yield-N Law is suggested as a useful empirical rule for mushroom culture if it is confirmed by experimentation.

A Plan for Putting this Theory to Practise

The research investigator will know how to go about testing this theory. But it may be a long time before sufficient data that will be

useful to the grower is available. Many fine details of procedure have to be explored; for example, it may be necessary to find out whether or not the percentage of N of mushrooms will vary when the mushrooms are picked from different beds of the same compost, or are of different size and age, or come from different breaks. Then again, from experimental results it may be evident that the N analyses of mushrooms are so variable, that such analyses are only significant when experimental plots are compared under identical environments, and so on. It should be abundantly clear by this time that only a theory or hypothesis is offered, not an accomplished fact. If the theory should prove to be untenable, it is hoped that modifications arising out of its investigation will be fruitful. In the meantime, for growers who would like to explore the possibilities of this theory for themselves, the following plan is suggested :

A. Keep a record of circumstances in preparing compost.
   1. Source of manure; 2. Estimate of amount and appearance of straw; 3. Other ingredients manure contains, or added; 4. Duration of composting, number of turnings; 5. Size and shape of heaps; 6. Weather during composting; 7. Temp. and duration of pasteurizing; etc.

B. Prepare and send mushrooms for N analysis.
   Pick about a pound of mushrooms of average size from first break. Slice and dry. Send to laboratory for moisture and N analysis. An analysis of the % K would also be helpful as previously described. (Laboratories of associations, spawnmakers, private or government. U.S. government grain laboratories, which make hundreds of N analyses daily, charge about $1.50 per analysis.) The analysis must be accurate to second decimal place, because small differences in % N correspond to large differences in yields.

C. Interpret N data according to yield and record. The yields from composts in which the % N of mushrooms was relatively low should be greater than from composts in which the % N was relatively high. It may be possible also that you can correlate the high yield according to data from your record; for example, if the yield was higher, the % N of mushroom lower, and the duration of composting shorter than for a comparable compost, then these data would tend to meet the requirements of a high C : N ratio, as previously discussed. On the other hand, if the yields from a compost in which the % N of mushroom was low, and yet the yield was relatively smaller, then according to the " N Law " other factors, independent of the specified compost, interfered with realizing the full yield potentiality of the crop. Such factors might be insects, diseases, casing, unfavourable environment, etc. If none of these factors offers a basis for explaining the discrepancy, then all that remains to be done is reject the " N Law ". But this " N Law " seems to be applicable in other fields of agriculture, and should serve as a valuable indicator of the yielding potentiality of a compost.

Conclusions

1. The main objective of this paper, how to account for the large yields recently reported, is explained as follows: In " short methods " of composting the loss of dry weight of material is relatively small, so that the carbonaceous material is present in a larger proportion to the nitrogenous material than would be the case if the duration of composting were prolonged. Accordingly, by this technique of composting, the result is a high C : N ratio. This relative dilution of N by a greater proportion of C is suggested as the basis for the operation of the " Inverse Yield-N Law." With more C available in the compost, the yield of mushrooms or sporophores is greater, but the sporophores contain less N. It is also suggested that in the mushroom nutrition the requirement for N may vary inversely as the need for K: so that, as the N is diluted by the larger supply of C, there is a greater requirement for K. The large amount of K in manure fills this requisition. Summarily, the high yields are explained on the basis of a high C : N ratio and a high K : N ratio.

2. The applicability of the " Inverse Yield-N Law " for mushroom culture, irrespective of the explanation above on the basis of a high C : N ratio, may be tested by analysing the mushrooms for N. If it is found that the yield varies inversely as the N content of the mushroom, then this "law" is applicable. Observing the inverse relationship between the % N and % K of the same mushroom specimen may be a more accurate procedure than merely comparing the % N of mushrooms from different composts. In evaluating data on N percentages of mushrooms, it is understood procedures will be standardized for selecting mushrooms for analysis, and for specifying the condition of the compost (i.e. C content, NPK, technique, etc.).

3. " The Principle of Limiting Factors " and the interrelationships of limiting factors are suggested as a basis for NPK formulations. The usefulness of a NPK formula are: 1. a means for selecting the least expensive source of NPK; 2. a basis for comparisons; 3. a basis for understanding the function and deviation of the major constituents of a compost.

4. Any NPK formulation is understood to be specific for a given carbon content of the compost, which refers to the carbonaceous material as determined at the end of the composting. It is suggested that the $N—P_2O_5—K_2O$ content of manure—2·0 : 1·0 : 2·7—may be the formula for preparing synthetic composts, which will produce high yields; on the other hand a 3 : 1 : 2 formula may be useful for producing sporophores with a high N content.

5. Cheese whey, and other carbohydrates inhibitory to " urea " bacteria, lignin, tannin, and gypsum may be useful in suppressing ammonification. Cheese whey is superior to gypsum as a suppressor of ammonification, but not as satisfactory for regulating moisture content; a combination of both may be required.

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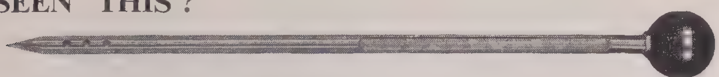
SEEN THIS ?



J. E. R. Simons Ltd. are marketing a new mercury-filled Soil-Sterilizing and Bed Thermometer with a distinctive easy-to-find *red plastic ball top* of $1\frac{3}{4}''$ diameter. The thermometer measures $16\frac{5}{8}''$ and its range is 30/240° F.

WHAT IS VERMICULITE ?

Vermiculite, the curious mineral product described by Dr. R. L. Edwards and P. B. Flegg in their article on page 205, was first tested as a casing material on mushroom beds at least six years ago, but without success.

More recently it was chosen as one of the ingredients of a series of artificial casing materials for experiments at Yaxley, on account of its great porosity and water absorption, and because it is sterile. Used alone for casing it has not so far given very satisfactory results, but mixed with peat it has given quite good yields. There is still much to be learned about the use of such mixtures, but vermiculite seems likely to interest mushroom growers increasingly as we learn more about it.

The name vermiculite is applied in commerce and industry to a group of platy laminated minerals that very much resemble, and may easily be mistaken for, inferior grades of mica. Compared with mica, Vermiculite is generally dried, soft and flaccid, lacking transparency and resilience and often possessing a somewhat soapy or talcose feel. But the most striking difference is noted when heat is applied.

When vermiculite is heated, the crystals expand to a remarkable extent in the direction perpendicular to the laminae. This curious bloating effect, known as exfoliation, is often so considerable that a plate of vermiculite, on heating, may swell up to some 20 times its original thickness in a manner resembling the opening of a concertina. The exfoliated product is not only very light in weight in comparison with its volume, but is also a good insulator for heat and sound, and many industrial uses for it have been developed during the past 25 years.

The name "vermiculite" is derived from the Latin and means literally "to breed worms"; it was originally given by T. B. Webb in 1824 to a mineral occurring at Milbury, Massachusetts, in allusion to its curious properties of developing into long, worm-like threads on heating. Subsequently, many other similar minerals have been described, all of which are known generally as vermiculites. They are monoclinic, hydrated, ferro-magnesian alumino-silicates.

Whether vermiculite is a true and distinct mineral species or merely a mixture of intergrowth of already known minerals was long in question. It is now recognised that there is a true vermiculite with a characteristic crystal lattice structure.

In commercial practice the term is used to denote any minerals of the type described that possess exfoliating properties of possible industrial application, whether or not they are true vermiculites in the mineralogical sense.

World production of vermiculite has been principally from the U.S.A., South Africa, the U.S.S.R., and to some extent from Australia. Most deposits of vermiculite are worked by open-cast mining. Cleanliness and accurate grading during the dressing process of the ore are important to produce a material of low bulk density, low thermal conductivity and greater compressive strength.

Exfoliation is carried out industrially by passing graded material through rotary, gravity or conveyor kilns, which may be heated by electricity, oil, pulverised coal or gas to temperatures between 600 and 900° C. and for periods between 4 seconds and 2 minutes. Freight considerations usually require exfoliating plants to be erected near consuming centres.

Vermiculite is used as a loose fill between suitable sheets, laths, wire netting or expanded metal for the thermal insulation of roofs, ceilings and walls. Exfoliated vermiculite in loose form possesses extremely good sound insulating and sound absorptive properties. Another most important application is its use as an aggregate for making light-weight concretes and plasters.

Its use in agricultural and horticultural field, such as beds for seedlings, casing material for mushrooms, and support for seedlings in hydroponics, has been considerably developed in the U.S.A. and South Rhodesia. Its use in horticulture is mainly indicated by the high water-absorptive property of the material and by its insulating properties in conjunction with surface temperatures.

Vermiculite is obtainable in several grades separated by sieving (the figures represent mesh to the square inch):

No.	British Standard Sieve Between	Density lb. per cu. ft.
1	18 and 36	
2	10 and 18	11·4
3	6 and 10	
5	$\frac{1}{4}''$ and 6	5·75
6	$\frac{1}{2}''$ and $\frac{1}{4}''$	3·8—4·1

Its pH value varies between 6·5 and 9·5.

MY WAY OF GROWING

11—Samuel Kohn *(Israel)*

Perhaps it may be of some interest to you to present a brief survey of the methods we use and have been using in this part of the world. To begin with, we changed within five years from growing mushrooms in caves to growing them in trays, meeting a number of difficulties on the way and so continuing the usual mushroom grower's life with its regular " ups " and " downs."

Our position is different, by far, from those where at least climatic conditions make mushroom growing quite a pleasant job. Looking back upon my visit to England, how I envy you British growers! You will probably be interested to learn that there are still places where, apart from the ordinary troubles of growing, exceptional snags present themselves quite often.

Our methods are just the ordinary methods and nothing can be told that would be exciting and new, or of special instructional value. The only way I can justify this report is by telling you about our hot conditions which make both cropping and marketing so very difficult.

Our settlement is situated in the north-western part of the hills of Galilee, three miles from the Mediterranean coast, and approximately 350 feet above sea level. Temperatures in summer reach 110° F. during the day and fall to 80° F. during the night. The Relative Humidity averages 90%—95% during the summer. In winter the average temperature is 50° F.—60° F. during the day and does not usually fall below 40° F. at night. The Relative Humidity is then very low 40%—70%.

You will see from these data that we are obliged to use a different method of ventilation and a different type of casing soil during the summer than in winter.

Winter is the main growing season, as good evaporation usually gives good crops, but, although preferable to the summer, the latter is the more " interesting " season.

In order to explain and describe our mushroom farm, it is necessary to give some information about our farm generally. The farm deals with practically all branches of agriculture as known in this country, namely, cattle, poultry, market-gardening, orchards, vineyards, and field crops covering an area of two thousand acres and employing altogether 250 workers daily. The farm is, of course, equipped with the necessary machinery, trucks, tractors, etc.

In our area tobacco has been grown very successfully for many years and two years ago we started to grow Virginia tobacco. The drying process of this brand demands the erection of special buildings. From the month of June until the month of September the tobacco is dried in these houses and temperatures of up to 180° F. are produced. by means of special stoves. At these temperatures the tobacco receives its golden colour. In early autumn the tobacco houses are cleaned out

and made ready to receive the mushroom trays. We only started last year to use these buildings and we are hoping the high temperatures of the tobacco drying will help us to avoid carry-over troubles. The five tobacco houses give us a total area of five thousand square feet.

It all began six years ago when we started to grow mushrooms in lime-stone caves without much knowledge about the job itself. The French ridge method resulted in the foreseeable fact that we had extremely high yields of Springtails, Mites and Flies, and there was hardly any need to remove the manure by mechanical means. These results led us to the decision to build a more suitable growing place, and we erected a special mushroom house with all the fittings dictated by the local climate.

This building is well insulated with cork and hollow concrete blocks and can be hermetically closed and also has a refrigerating plant attached. Peak heat is reached easily, usually by normal fermentation and in difficult cases by electric heating. This plant contains three rooms, altogether six thousand square feet of shelf-beds.

The third type of building we use contains two rooms, each with three thousand square feet. This house is only suitable for winter production. All houses are of the American type.

In summer we grow mushrooms only in the cooled building. We use a light type of terra rossa as casing, which somehow releases some water even under bad conditions.

With regard to marketing we, too, have our problems in the summer months—heavy loss of weight, for example, as well as other climatic influences on the quality and freshness of the product.

As far as manure is concerned, we are able to choose from all suitable varieties. The soil on and around our farm is slightly alkaline—pH 7·6—well aerated, with a good water-holding capacity, and until recently we did not find much difference between the top and subsoil. Anyway, we see in the choosing of the soil the key to success or failure. A lot of experimenting has still to be done here with regard to the right type of casing soil. The hardest problem is ventilation during the hot summer nights. Even the most lumpy soil develops stroma. The use of Dithane—your zineb—seems to help sometimes to overcome this difficulty. It is most important during this season to make a careful choice of the most suitable type of casing soil, and ventilation problems must be painstakingly tackled.

In the course of six years we have succeeded in growing *Dactylium*, White Plaster, Brown Plaster, *Clitocybe dealbata*, and Truffle! Luckily, these troubles occured in isolated spots and did not recurr. Besides these fungi, of course, we get some mushrooms; the average yield is 2 lb. per square foot during the summer. We have no doubt, however, that it is possible to increase this yield by a thorough investigation of the local conditions and problems. We have to solve most of our problems ourselves without outside advice as there is not yet a Mushroom Growers' Association or Mushroom Research Association in Israel.

Finally, I should like to mention that we owe much of our achievements to the Yaxley station and the MGA which constantly help us by prompt advice and answer all our inquiries. Needless to say, every copy of the Bulletin is very valuable to us, as there are very few local growers with whom we can exchange experiences and ideas.

We are indebted to THE GROWER *(2.5.53) for permission to reproduce the following extracts:*

THE MANURE CASE

William Henry Stevens, one of the biggest manure dealers in the south of England, was sentenced to two-and-a-half years in prison and ordered to pay up to £1,500 costs at the Assizes at Chelmsford on 30th April. The trial lasted two weeks.

His manager and five lorry drivers were also sent to prison. All had been found guilty of conspiring to defraud racehorse trainers from whom they bought manure, and growers to whom they sold it. The sentences were:

William Henry Stevens, 39, managing director, of Clayhill, Enfield, was sentenced to 30 months and costs not exceeding £1,500.

John Daniel Alfred Lovell, 38, manager, of The Bungalow, Stevens' Depot, Thornwood, Epping, to 18 months.

On the lorry drivers: Sturdee Bunn, 38, The Caravan, Stevens' Depot, Epping, 16 months; George T. Dawkins, 37, Pyrles Lane, Loughton, 14 months; Albert Smith, 32, Queensway, Exning, 12 months; Valentine King, 27, George Avenue, Exning, 10 months.

Arthur J. Brickstock, of Frampton Road, Epping, was conditionally discharged.

Stevens and Lovell were acquitted on one charge of obtaining money from a nurseryman.

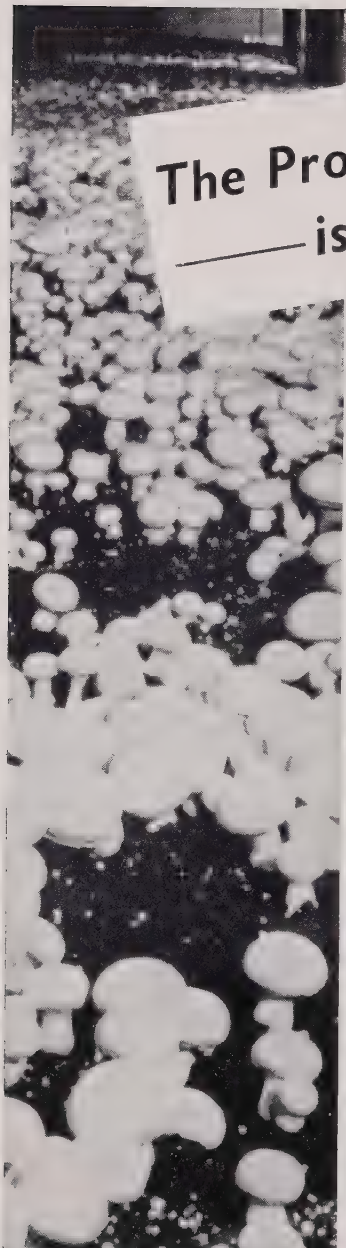
After the verdict Mr. Justice Hallet told Stevens: " You were the head of this firm. There is no doubt whatever of the justice of the verdict. When you were swearing, as Lovell was, that you were trusting the drivers, you actually knew that in 1948 Bunn had on eight occasions forged and uttered weighbridge tickets, and had been dealt with leniently for those offences.

" It was into your pocket ", said his Lordship, " that the bulk of the sum, gained by these means, passed.

" It was a prolonged and widespread conspiracy lasting two and a half years. You stopped only when the police were hot on your track.

" The case has cost the public a very large sum of money. Since you have been, and probably still are, a man of very considerable means, I see no reason why the whole of that expense should fall on the public of this county ".

To Lovell his Lordship said: " There is no evidence that you had any direct monetary gains. It would have required great moral courage for you, Stevens's right-hand man, to cut yourself away ".



The Glasshouse Area down to mushrooms on 15th January this year was 40 *acres*, compared with 38 a year ago, according to the Ministry of Agriculture.

HETP and **TEPP** are among the insecticides which can now be used only if employees working with them are wearing protective clothing. This is one of the Regulations under the Agriculture (Poisonous Substances) Act, 1952, which came into force on 31st March this year.

Monsieur P. Guiochon, of Mesnil-le-Roy, (S. et O.), president of the French Federation of Mushroom Growers, is anxious for his 23-year-old son to spend two months on a mushroom farm in England, where he could improve his English and study our methods. Monsieur Guiochon asks if any MGA member would take him on as a workman, without payment of course; in return he would be happy to offer similar facilities in France.

W. DYKE'S FORMULA

W. Dyke writes to *The Commercial Grower* (9.4.53) from Netherall Nursery, Roydon, nr. Ware, Herts., as follows:

Having recently spent a considerable amount of time on the making of a synthetic compost for mushroom beds, I think I can help growers in making one very reliable, and not too costly. It would be composed entirely of wheat straw, ammonium nitrate, muriate and sulphate of potash, and superphosphate.

There is one way some of your readers could be of real assistance to me at the present time. I have an idea the following would supply the food the mushroom needs for its growth and development, and any Boots' chemists would make it up. Formula: 1 oz. of ammonium nitrate, $\frac{1}{2}$ oz. of dihydrogen potassium phosphate, $\frac{1}{4}$ oz. of magnesium sulphate, a trace of iron chloride, and 5 oz. of glucose sugar.

This should be dissolved in six gallons of water. The growers to whom I am appealing, are those who have a bed that has produced a good crop of mushrooms but is worn out. Water one half with the above water and solution, and the other with the same quantity of water.

BROWN BLOTCH

A brown blotch disease of cultivated mushrooms caused by *Pseudomonas tolaasi* Paine has been studied. It turned out that, for artificial infection, the bacteria needed substances extracted from meat or mushrooms. The mushroom extracts could be obtained from pilei and from pure culture mycelium with hot as well as cold water. The cold water extracts probably show the way by which natural infection on the beds occurs. Old mycelium in the casing soil and stumps of mushrooms, left on the beds after picking, together with the sprayed water might provide for the substances and help infection. Trashing the beds will cut down the rate of blotched mushrooms. *Pseudomonas tolaasi* proved to be resistant to the bactericides tried.

A brown blotch disease of cultivated mushrooms caused by Pseudomonas tolaasi Paine, by H. C. Bels-Koning and K. de Jong-Olthof. (In Dutch.)

Stanley Middlebrook's Diary

Apl. 10. I wonder how many failures are caused by running spawn at too low a temperature. We are apt to become rather too casual about spawn runs and tend to forget the heat requirements. Worse still, we are apt to case after three weeks whether spawn is properly run or not on the assumption that " it must have ". It is fatal to case on a bad run, in my opinion.

Apl. 14. Perhaps mushrooms grow best in spring. Perhaps, too, it is in spring that they are at their least interesting. With freshening colour and the cheerfulness of new green life in all other horticultural pursuits the monotonous monochrome of mushroom making is a drab and dismal affair. This sets me thinking. How like the four seasons is the cycle of a mushroom crop. The first pinheads break through and give a lively, clean, optimistic first flush—that is spring. The crop matures into its second, third and fourth flushes, the atmosphere dries, the mushrooms while still coming pretty thickly begin to have a tiring look as their summer leads to their autumn of weakened and decaying growth with competing fungi an ever-increasing threat. They fade and die. The winter of the cycle arrives and houses are as bare of fruit and hope as a tree is of leaves. (The Bard of Brayton.)

Apl. 17. Six or seven trays in a house containing 250 have produced completely gill-less mushrooms through most of their six-week cropping period. These curious trays were in various parts of the house—not all together in one spot. No possible explanation so far.

Apl. 18. Last month the editor blue-pencilled a note on spawn, consulted or was consulted by a spawn maker, and to save his own skin pushed the maker on to me. The latter went for me tooth and nail. Why? Who'd mentioned *his* spawn? I suspect the cap must have fitted—in his opinion. The spawn in question grew a sort of fine dark-coloured mould mycelium, almost resembling a powder. It grew rapidly. Why do I blame the spawn? Because it emanated therefrom just as mushroom mycelium will. A second spawning—same make—started to grow out from the —er—base but found the dark powder-like mycelium too much for it. The whole lot had to be thrown out. I'm sorry, Editor, but it's the truth and the truth should not be hidden.

Apl. 21. Said a traveller to-day "A lot of growers like to see us commercials—it's the only way they can get to know what other growers are doing ". I think he was a little unfair to himself and his sort. Mushroom travellers don't talk too much about other growers except perhaps as their best advertisements. Nevertheless odds and ends of information do slip out occasionally and one is amused at the variations between the salesman's and the grower's versions of the latter's progress—when one later talks to the grower. It's not impossible that the salesman is more hopeful of your order if he can hint that you're way ahead of your competitors.

Apl. 30. Research certainly simplifies growing! At one time—within living memory—we simply used soil as a casing medium. But now

scientists—and some adventurous growers— present many alternatives. So we now have peat and vermiculite; peat and sand; peat and ashes; peat and chalk; peat and lime; peat and gravel; or just peat. Or we can have peat and vermiculite and ashes and sand and lime and gravel all at once. Alternatively we have the choice of ashes and sand; ashes and chalk; ashes and vermiculite; ashes and peat (or have we tried that already?). The possible combinations are legion. As these materials are " synthetic " there will of course be no watering or ventilation problems, and thicknesses won't matter at all. Be warned, Grower. You once had a simple casing material. It wasn't perfect but it was all you had and you made the best of it. What do you do now? You try peat and vermiculite then hear that so and so does remarkably well on peat and ashes; then hear by chance or from the horse's mouth that peat alone is producing 3 lb. in no time. You switch from one to another—and what a lot of others there are. Finally you get nowhere. Road sweepings and ashes (collected in sackcloth) may be the final attempt.

May 1. It's only a matter of time now before our tray houses are converted back to shelves. We're all looking forward to the happy day.

May 4. I have two cuttings before me. One is Robert Patterson's latest article in *Commercial Grower*—and how pleasantly our old friend " Pat " writes; why doesn't our editor do something about it? In this article he says " some beginners have the mistaken idea that mushrooms can be grown as a sort of side line to fill in spare time . . . . . . he will soon be disillusioned . . . . . . mushrooms will not put up with haphazard ' hole in the corner ' methods." He adds that time and attention are required and neglect will soon reap its own rewards. The second cutting is a review of Roy Genders' new book *Mushroom Growing at Home*. To this author is attributed the statement that " Mushrooms are so accommodating that one could leave home for a month and return to find them none the worse ". I leave my readers to decide which version is correct. I've little doubt of the answer.

May 5. Yesterday an agent tried to sell me some of his firm's product. " Safe as houses and cheap to use—better than anything else." For the sake of example we'll say it was an insecticide (but it wasn't, so I can't get myself into trouble!). To-day a sundriesman who handles this product for other uses than mushroom growing could not sell me any because the maker had authorized his firm (and presumably similar firms) not to sell it to mushroom growers for any purpose whatever to do with mushroom cultivation. Surely this is odd; if it's O.K. when the makers sell it why isn't it if anyone else does?

May 7. Can a " young man " have mushroom experience? Evidently an American advertiser in this issue thinks so. They once took our spawn over there, improved on it, and sent us the result. Perhaps they want our young fellows to improve them (in a mushroom sense) and send them back to us. I wonder. I still think we can show them a thing or two—small things perhaps, but nevertheless important. It's interesting, however, that the approach is through the MGA. It looks like a golden opportunity for some young fellow. Twenty years ago I might have applied, but . . . . . . well, they do ask for experience!

RESEARCH APPEAL, 1953

Among the contributions received during April towards the maintenance of Yaxley Research Station was a much appreciated £20 from Monsieur **Guy de Man,** of Sobexas. He and the other contributors listed below are thanked by the MRA Directors for their support.

We are barely two-thirds of the way towards our target. *Will all who have not yet sent a donation please do so as soon as possible*? It is particularly important this year.

	£	s.	d.
de Man, G. (Belgium) ..	20	0	0
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Bradford Fertilizer Co. Ltd.	2	2	0
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Read, I. W. (Australia) ..	2	2	0
Weatherall, Lt. Col. N. ..	2	0	0
Barraclough, H.	1	1	0
Gardner, R. W.	1	1	0
Leach, T. T.	1	1	0
Boland, Miss E. M. ..	1	0	0
Bankers' Orders (April) ..	10	0	0
	81	6	0
B./F. from April Bulletin ..	753	17	0
	£835	3	0

In the April Bulletin was recorded £6 13s. 0d. received from Mr. A. Beck, of South Africa. This should have read South America.

Paper given at Peterborough Refresher Course, 16th April, 1953

SOME ARTIFICIAL MIXTURES USED IN CASING SOIL EXPERIMENTS

By **Dr. R. L. EDWARDS and P. B. FLEGG**

Our object in this talk is to explain:—(1) how and why we came to start the experiments which many of you have heard about lately, (2) how far we have got, (3) what remains to be done, and (4) what are the prospects for the future.

We have thought for several years, as others have, that among the important properties of a casing soil were its capacity for holding water which could be given up when needed, and its porosity to air. It does not matter very much for the moment whether the soil gives up its water directly to the mushroom, or merely uses it to humidify the air and so prevent drying of the mushroom, or even uses it in some other way which we do not at present understand.

Porosity to air is needed so that the mushroom mycelium can breathe and so that the carbon dioxide which it produces, and possibly other products, can escape from the bed.

We have spent some time during the past year examining soils and other possible materials for these properties by laboratory tests. From the data collected in this way we made up series of mixtures for use in casing experiments, in which we could vary separately the moisture holding capacity, the air space in the dry material, or the air space in the wet material, each to a considerable extent independently of the others. Our object was to find out whether any of these properties, moisture holding, pore space, wet or dry, had direct relation to yield, or perhaps to number of mushrooms obtained, time of fruiting, or other cropping effect.

Four materials were used in these mixtures:—1. our own clay loam subsoil; 2. sand; 3. an imported sphagnum peat; 4. vermiculite, medium grade, and later other grades.

We do not claim that the idea of using these materials for casing was new. Over 50 mixtures have been made up and tested.

Unfortunately for our objective, the vermiculite when used alone or with sand appears to have some toxic properties which delay fruiting. We think this is due to its magnesium content, and the effect is absent or smaller in mixtures with clay or peat. This is quite reasonable on theoretical grounds.

This toxic effect spoiled some of our selected ranges, but even apart from these we have not so far found any relation of the kind we were seeking between physical properties and cropping. The experiments so far have been on a very small scale, and we have not abandoned that line of attack.

Commercial Tests

While this work was in progress various growers who called at the research station were very interested in the idea of artificial casings,

and one or two who have great difficulty with their casing soil decided that they would like to try some on their own farms.

We did not consider that our own state of progress warranted commercial trial, and said so, but had no reason for refusing information about the mixtures used. Several growers have therefore cased small areas on their own farms with one or more of these mixtures, entirely on their own initiative and at their own risk. Their experiments are not sponsored or supervised by the Research Station, and we have no check on the reliability of their results or on possible effects of other changes in methods, nor any right to publish them. All we can say is that some growers who have previously had difficulty with their normal casing soil, have had better results with some of these mixtures.

The most promising are a mixture of equal volumes (measured dry) of peat and vermiculite, and a mixture of equal volumes of peat and sand. The peat used was the imported fibrous sphagnum peat, and its acidity must of course be neutralised with some form of lime; we use carbonate.

In starting this work we had two ultimate objects in view, a completely artificial casing, or enough knowledge to enable us to improve poor soils by fairly simple standardised additions, or of course both of these. In view of the promise held out by these mixtures we have modified our programme to pursue the first of these objects more directly.

Gaps in our knowledge

There were when we first found their promise, and there still are very large gaps in our knowledge. Some of these would apply to any new casing material; some are due to our general ignorance about the best treatment of casing soil except within the limits of one soil on one farm; all of them are magnified by the very different properties of these mixtures, particularly peat-vermiculite, compared with soil.

We did not know at first, but have some idea now, how wet the casing should be when it is put on the beds. We think it should be put on as wet as it can be made.

We still do not know how often or how heavily it should be watered, and we have not even a basis for comparison with soil under one set of conditions.

We suspect that depth may be more important than it is with soil, and that greater depth may be needed, but we do not really know.

We are fairly sure that size of vermiculite matters, the fine grades being unsuitable when mixed with sand, but we do not know how important this is in mixtures with peat, nor what are the size limits for successful use.

We do not know whether any kind of peat will do, three samples are now undergoing cropping trials.

Experiments are now in progress to compare peat-sand and peat-vermiculite with our own soil, and also on watering, depth, and use of other peats.

SUMMARY

To summarise the position so far, we have enough evidence to show that two mixtures, peat-vermiculite and peat-sand, each in equal parts by volume are worth trial by any grower with a poor soil. The vermiculite

should not be less than $\frac{1}{8}''$ mesh and we have used an imported sphagnum peat. The peat must be limed to bring the pH of the final mixture to about 7·5, and the mixture should be applied thoroughly wet. The casing should be not less than $1\frac{1}{4}''$ deep, $1\frac{1}{2}''$ may be better.

These casings do not confer immunity from pests or disease, though they may not be such prolific carriers as some soils.

The cost is somewhere in the region of 2d. per sq. ft., not allowing for mixing and application; this is higher than most soils, but the mixtures are lighter to handle, and if they give better crops, it only takes an extra ounce per sq. ft. to pay for them.

We shall know more about them in a few years time, and there is every prospect that they will solve the casing soil problem for growers who have not a good soil handy.

"Of course this means the end of the horse."

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